Cloud Computing: Some Implications for Key Management

June 8, 2009

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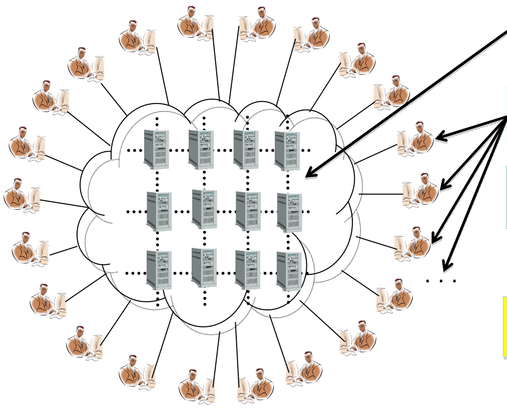
For those viewing via webcast, please submit questions for this presentation to kmwquestions@nist.gov"

Cloud Computing: Still Being Defined



Computers in a network, providing service.

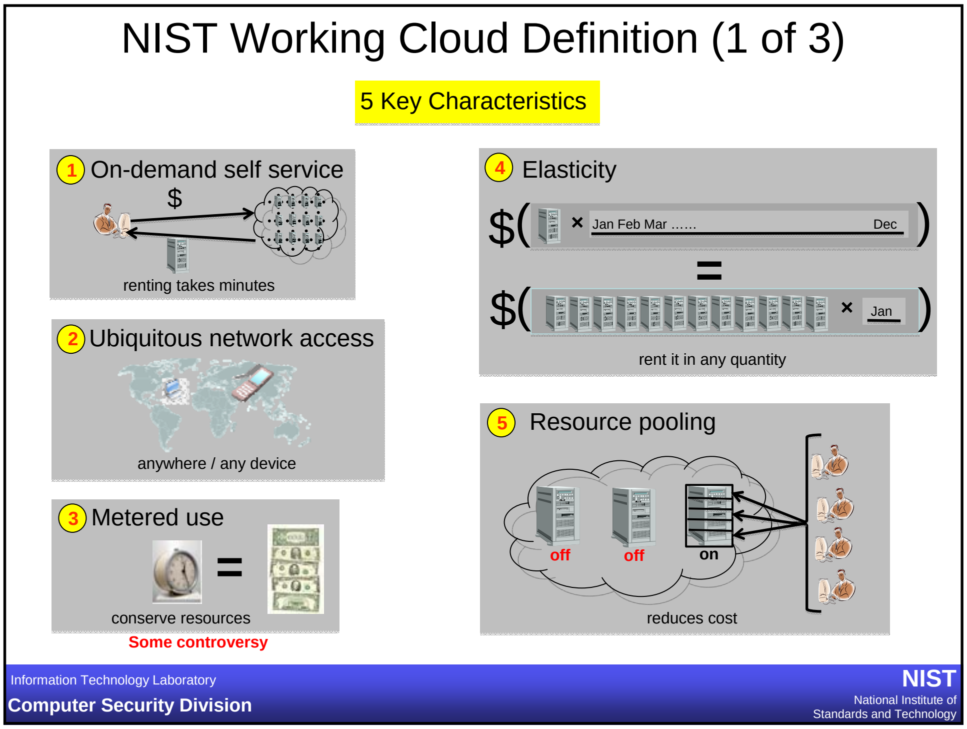
Users with network access.

Convenient remote computer rental.

In any quantity.

"Feels" local.

A technical or business innovation?



NIST Working Cloud Definition (1 of 3)

5 Key Characteristics

1 On-demand self service

$

renting takes minutes

2 Ubiquitous network access

anywhere / any device

3 Metered use

=

conserve resources

Some controversy

4 Elasticity

$(× Jan Feb Mar …… Dec)

=

$(× Jan)

rent it in any quantity

5 Resource pooling

off

off

on

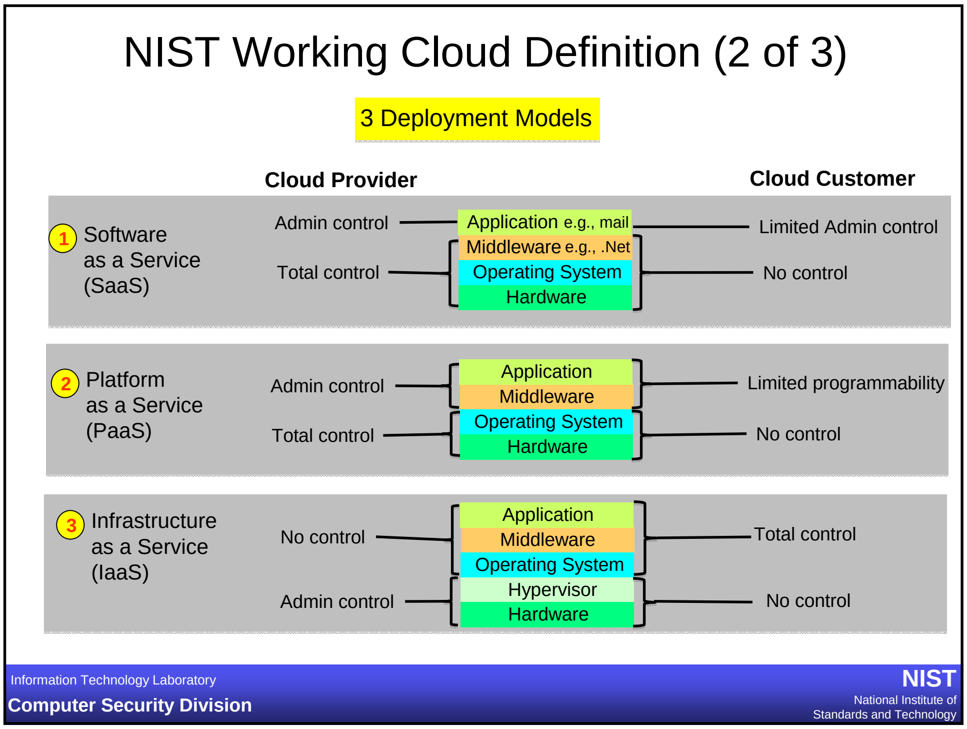
reduces cost

Information Technology Laboratory

Computer Security Division

NIST

National Institute of Standards and Technology



NIST Working Cloud Definition (2 of 3)

3 Deployment Models

Cloud Provider

Cloud Customer

1 Software as a Service (SaaS)

Admin control — Application e.g., mail — Limited Admin control

Total control — Middleware e.g., .Net / Operating System / Hardware — No control

2 Platform as a Service (PaaS)

Admin control — Application / Middleware — Limited programmability

Total control — Operating System / Hardware — No control

3 Infrastructure as a Service (IaaS)

No control — Application / Middleware / Operating System — Total control

Admin control — Hypervisor / Hardware — No control

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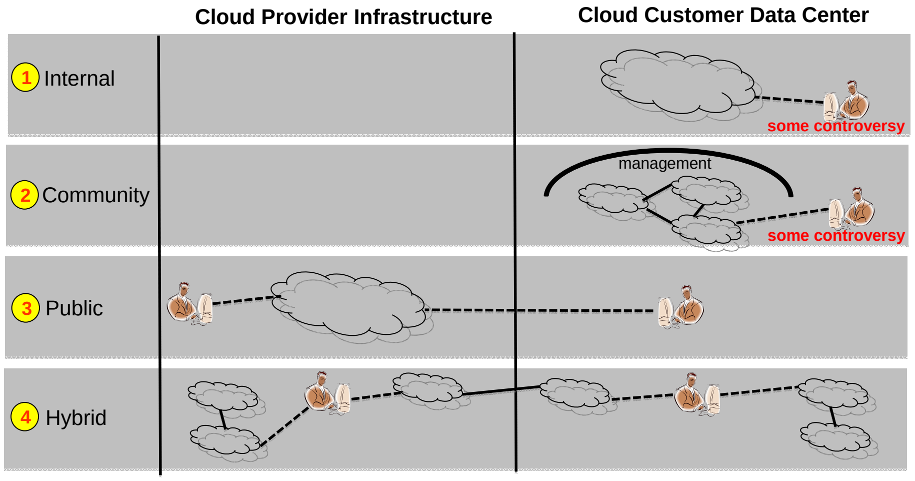
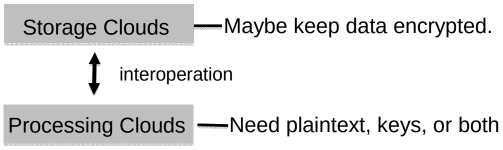
NIST Working Cloud Definition (3 of 3)

4 Delivery Models



A few more Cloud Aspects

1 There are two basic kinds of clouds:



2 Both **require** extremely fast & reliable & secure & low-cost **networking**.

3 Clouds are a good fit for very large scale processing/storage, using new algorithms:

Map Reduce
Bigtable
Google File System

Why Care?

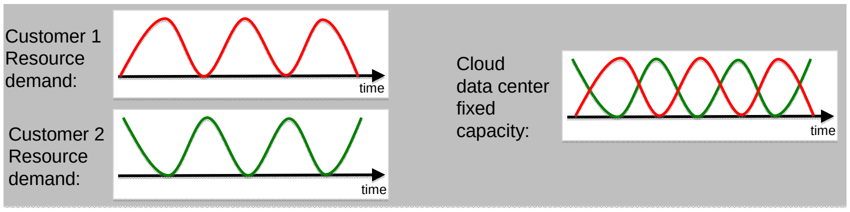
1 Clouds capture economies of scale.

In 2006, large data center cost advantage: 5.7 to 7.1 times.

Credit: [Ham], summarized in [Arm].

2 Clouds can locate computing close to low-cost power, land.

3 Clouds make it easier to provision for actual (fluctuating) loads.



Customer 1 Resource demand:

Customer 2 Resource demand:

Cloud data center fixed capacity:

Provide the illusion of infinite resources (to customers). If there is demand diversity.

4 Clouds enable rapid, low commitment, infrastructure for short term (or new) projects.

Who Cares?

- Amazon
- Microsoft
- Google App Engine
- Salesforce
- IBM blue cloud
- Vmware
- Sun/Oracle
- Force.com
- …

- Open Cloud Consortium
- Vivek Kundra, fed CIO
- Distributed Management Task Force

And more.

Credit: http://www.johnmwillis.com/cloud-computing/cloud-vendors-a-to-z-revised/

Sample Cloud Interface (Amazon EC2)

43 customer-callable functions:
(SOAP, Query, command-line)

Operate your own cloud resources.
All operations digitally signed.

Amazon Machine Image: 4	Key Pairs: 3
Availability Zones/Regions: 2	Monitoring: 2 Images: 2
Block Store Management: 8 (snapshot)	Reserved Instances: 3
IP Addresses management: 5	Security Groups: 5
Instances: 4	MS Windows specific: 3

Credit: aws.amazon.com

(not an endorsement)

A Quick Trip Through the (simplified) API

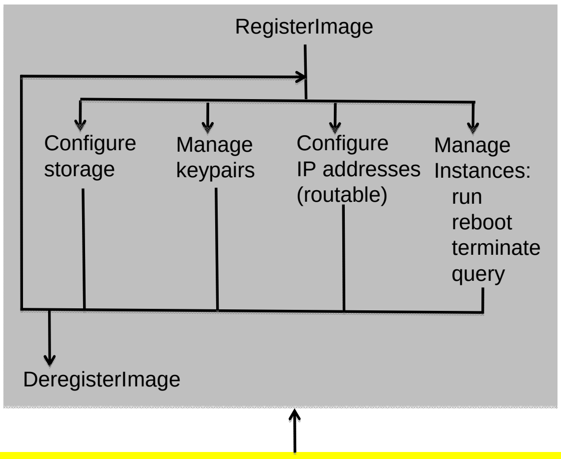
Setting up:

TLS
- aws.amazon.com
- create account
- set password
- email confirmation
- PEM-encoded
  - RSA private key
  - x.509 cert

CreateKeyPair

Use to talk with new VMs

Steady state (simplified)



Every operation digitally signed.
Every key pair public key stored in the cloud infrastructure.

Credit: [Sos], aws.amazon.com

Key Management

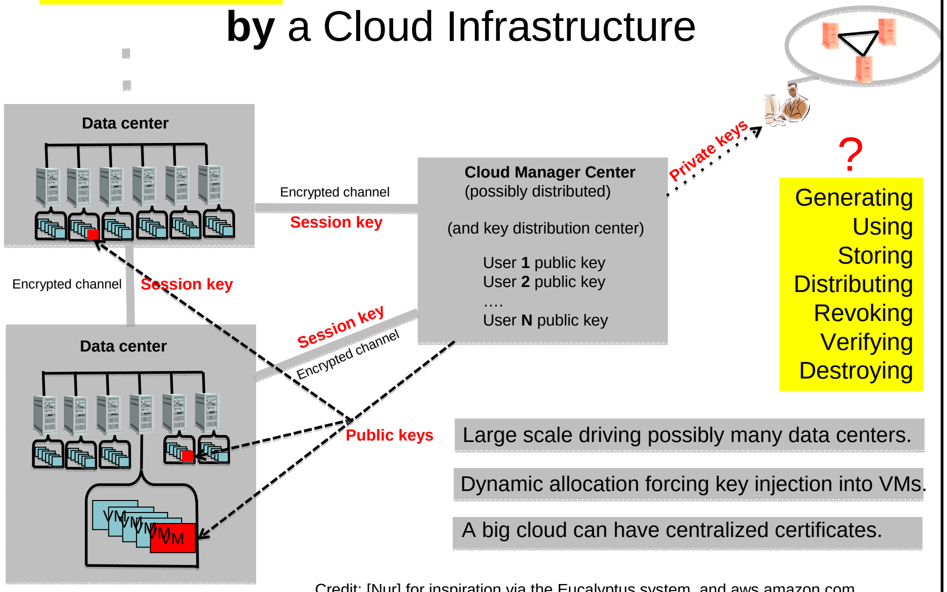
Key Management:

Generating keys	Using keys	Storing keys
Distributing keys	Revoking keys	. . .
Verifying keys	Destroying keys	

Bold assertion: there are two basic scenarios:

1. Key management conducted by the cloud infrastructure itself.
2. Key management conducted by computations that have been entrusted to run in the cloud infrastructure

Speculation: How Keys Might Get Managed **by** a Cloud Infrastructure



Generating
Using
Storing
Distributing
Revoking
Verifying
Destroying

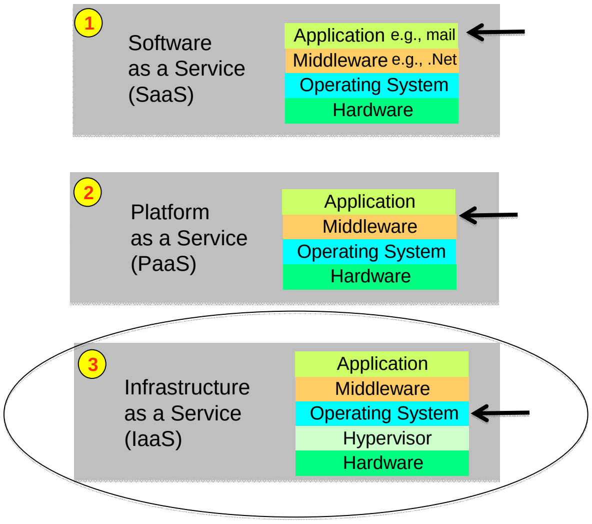
Large scale driving possibly many data centers.

Dynamic allocation forcing key injection into VMs.

A big cloud can have centralized certificates.

Credit: [Nur] for inspiration via the Eucalyptus system, and aws.amazon.com.

Execution Environments for Cloud-Hosted Key Management



1 Software as a Service (SaaS)

Application e.g., mail
Middleware e.g., .Net
Operating System
Hardware

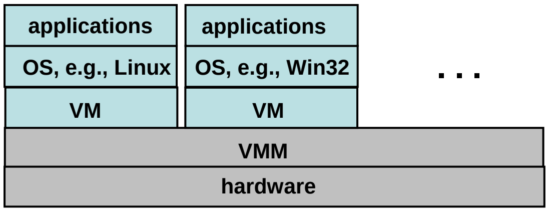
2 Platform as a Service (PaaS)

Application
Middleware
Operating System
Hardware

3 Infrastructure as a Service (IaaS)

Application
Middleware
Operating System
Hypervisor
Hardware

Hardware Virtualization



applications | applications
OS, e.g., Linux | OS, e.g., Win32
VM | VM
. . .
VMM
hardware

- A simple picture!
- But implementation is complex.
- Virtual Machines (VMs) can be:
  - suspended/copied/moved/lost/recovered.

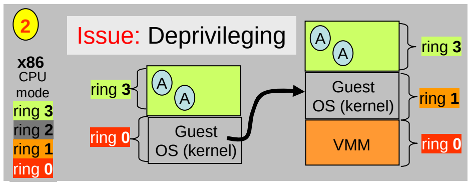
Hardware Virtualization

(Simple View)

1

Terminology

Guest OS : runs only on VMM
Host OS : runs only on HW
Domain : virtual machine on VMM
Hypervisor : virtual machine monitor



In 2000, the Pentium had 250 instructions, 18 that were not virtualizable. Binary translation, however, could virtualization them anyway.

Making x86 Virtualizable

Using Extra Hardware

Intel 64

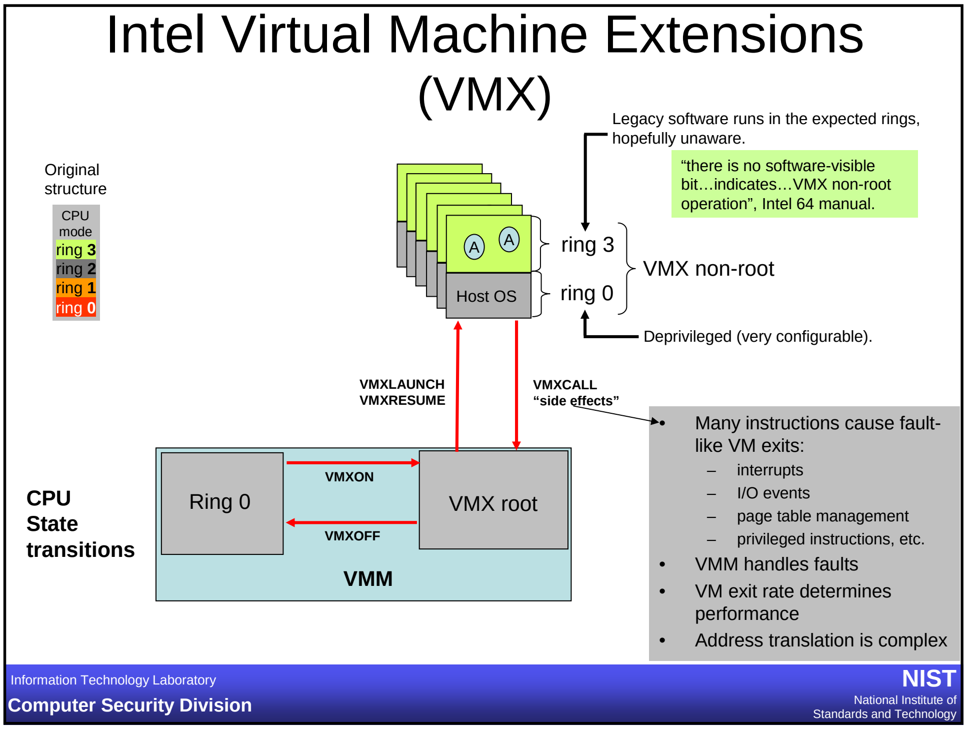
- Intel version of **x86-64**
- contains ~**595 instructions**.
- Hardware extensions make the instruction set virtualizable

Floating Point	
Data	17
Arithmetic	26
Compare	14
Transcendental	8
Constants	7
Control	20
State management	2
	94

SIMD	
MMX	47
SSE	62
SSE2	69
SSE3	13
SSSE3	32
SSE4	54
	277

General Purpose	
Data transfer	32
Arithmetic	18
Logical	4
Shift/rotate	9
Bit/byte	23
Control transfer	31
String	18
I/O	8
Enter/leave	2
Flag control	11
Segment register	5
Misc	6
	167

VT-x Extensions	**12**
Safe mode	**1**
System	**34**
64-bit mode	**10**



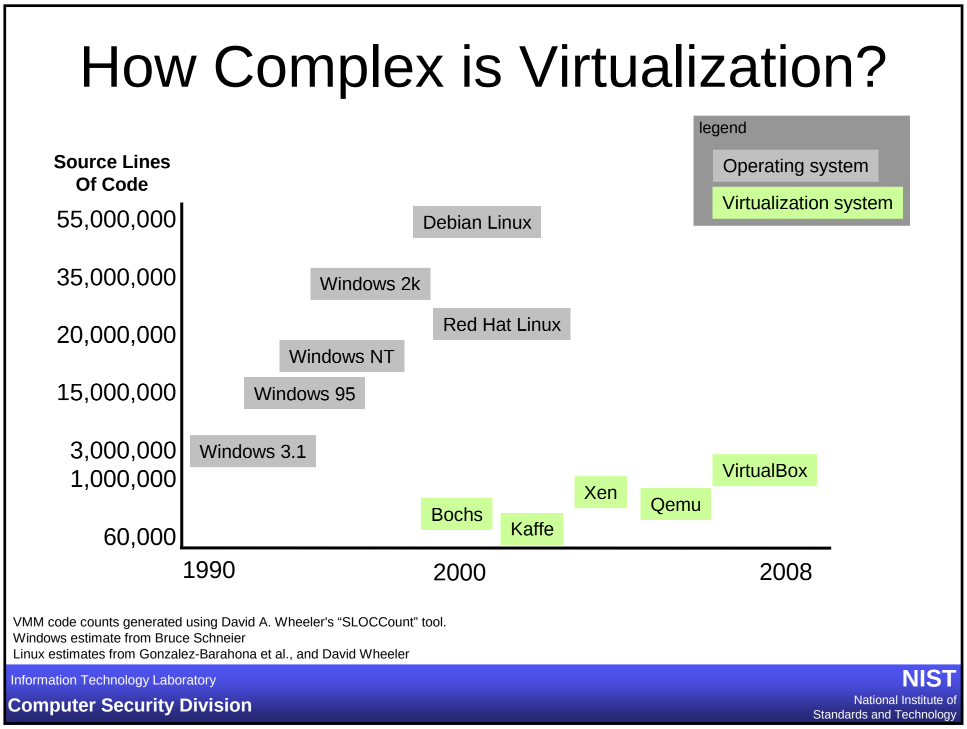
Intel Virtual Machine Extensions (VMX)

Legacy software runs in the expected rings, hopefully unaware.

“there is no software-visible bit…indicates…VMX non-root operation”, Intel 64 manual.

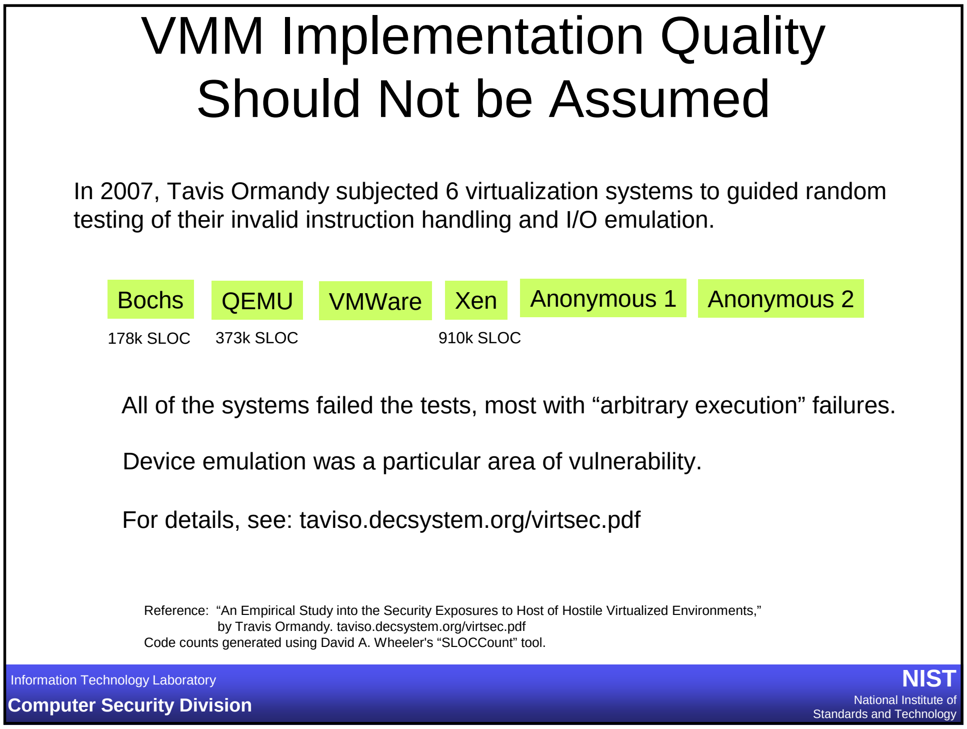
Deprivileged (very configurable).

- Many instructions cause fault-like VM exits:
  - interrupts
  - I/O events
  - page table management
  - privileged instructions, etc.
- VMM handles faults
- VM exit rate determines performance
- Address translation is complex



How Complex is Virtualization?

VMM code counts generated using David A. Wheeler's “SLOCCount” tool.
Windows estimate from Bruce Schneier
Linux estimates from Gonzalez-Barahona et al., and David Wheeler



VMM Implementation Quality Should Not be Assumed

In 2007, Tavis Ormandy subjected 6 virtualization systems to guided random testing of their invalid instruction handling and I/O emulation.

Bochs	QEMU	VMWare	Xen	Anonymous 1	Anonymous 2
178k SLOC	373k SLOC		910k SLOC		

All of the systems failed the tests, most with "arbitrary execution" failures.

Device emulation was a particular area of vulnerability.

For details, see: taviso.decsystem.org/virtsec.pdf

Reference: "An Empirical Study into the Security Exposures to Host of Hostile Virtualized Environments,"
by Travis Ormandy. taviso.decsystem.org/virtsec.pdf
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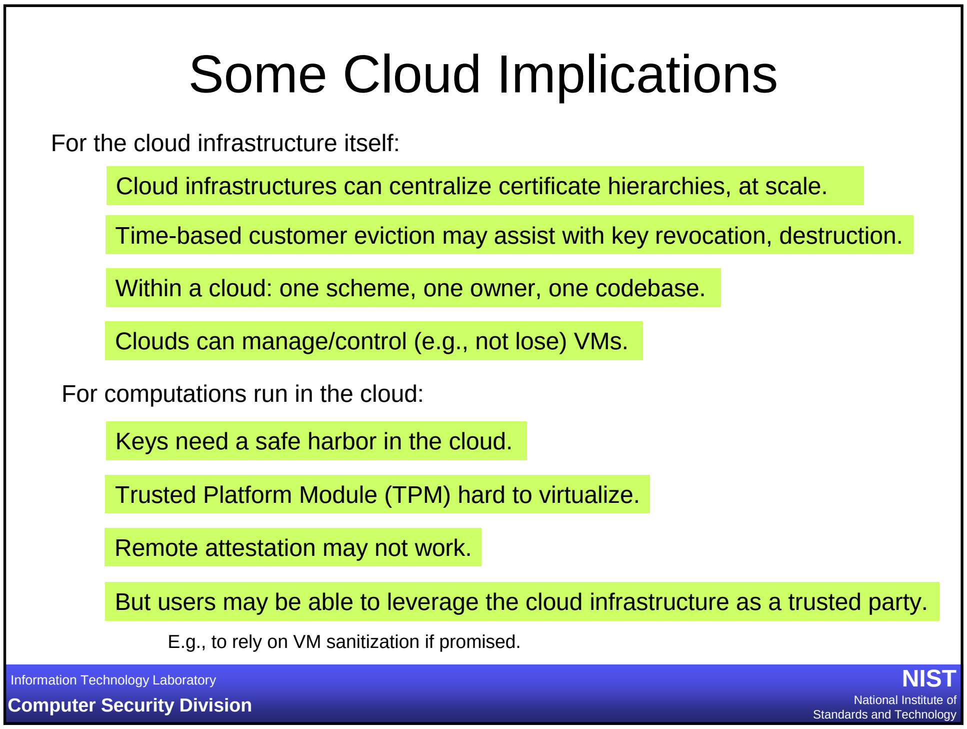

Some Cloud Implications

For the cloud infrastructure itself:

- Cloud infrastructures can centralize certificate hierarchies, at scale.
- Time-based customer eviction may assist with key revocation, destruction.
- Within a cloud: one scheme, one owner, one codebase.
- Clouds can manage/control (e.g., not lose) VMs.

For computations run in the cloud:

- Keys need a safe harbor in the cloud.
- Trusted Platform Module (TPM) hard to virtualize.
- Remote attestation may not work.
- But users may be able to leverage the cloud infrastructure as a trusted party.

E.g., to rely on VM sanitization if promised.

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